G. Genon, D. Panepinto, F. Viggiano,
Politecnico di Torino, Italia

BIOENERGY: POSITIVE ASPECTS AND SUSTAINABILITY

Introduction

Climate change is the primary worldwide issue of the 21st century, as it threatens not only natural ecosystems but many national economies as well. Since the major contributor to climate change is the emission of greenhouse gases, switching to renewable and clean sources of energy production would result in the most immediate benefit. And one of the main energy sources in this category is biomass [1, 2].

In comparison with fossil fuels, the carbon dioxide generated in the combustion of biofuels is not considered to make any net contribution to the CO_2 content of the atmosphere, since CO_2 is absorbed by the photosynthesis of living biomass [3]. Biomass, therefore, is widely considered to be a major potential fuel and renewable resource for the future [4–9]. Energy from biomass based on short rotation forestry and from other energy crops can contribute significantly to the objectives of the Kyoto Agreement in order to reduce greenhouse gases emissions and consequently in order to obtain solution for the problems related to climate change [10, 11].

In this context, in the present work, we studied the proposed realization of bioenergy plants from different points of view; in order to verify the environmental acceptability (compatibility) of the biomass plants, we performed an evaluation of the modification of emissive fluxes at both local and global levels. Together we considered planning, and social acceptability criteria.

Technological consolidated and advanced schemes

A schematic view of the wide variety of bioenergy routes can be found in Fig. 1 [12], the indicated processes are an indication of the different types of feedstock that can be used, the conversion routes (comprehensive of pre-treatment and feedstock energetic valorisation), the final products in terms of produced heat, power, final products (chemicals or biofuels).

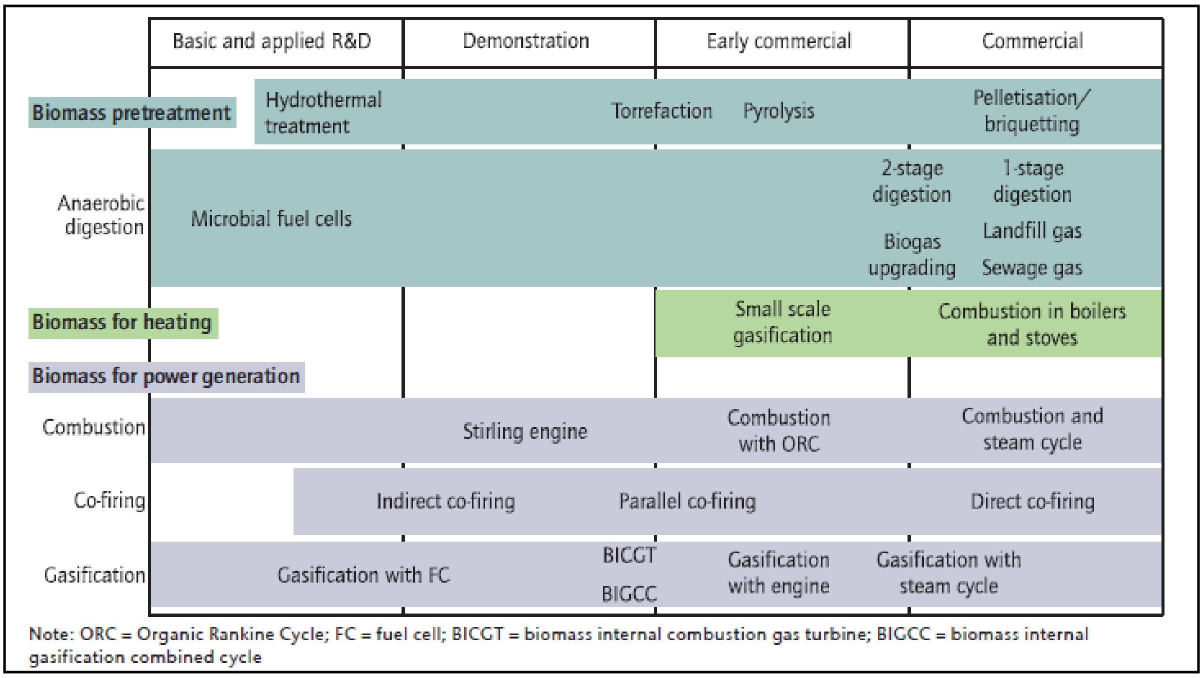

Fig. 1. Overview of conversion technologies and their current development status [12]

As concerns the strict technological aspect, these considerations can be done:

– the direct biomass combustion for heating is a well developed technology, but frequently it is characterised by low efficiency, and severe phenomena of smoke pollution; modern technologies like MSW incineration and use of biogas can improve these critical aspects;

– biomass-based power plants present medium efficiencies (lower than fossil fuel thermoelectric plants), therefore possibilities for co-firing in existing conventional plants must be considered;

– thermal gasification is a promising route, both form the point of view of efficiency and of containment of environmental impact, but the reliability of these plants still needs further verification;

– biorefineries can lead to production of biofuels and other chemicals, and in particular today there is an increasing interest in cellulosic ethanol plants, where an higher compatibility can be observed;

– the technology of carbon capture and storage applied in bioenergy conversion plants, leading to removal of CO2 from atmosphere and injection in a long term geological storage with a global negative emission is a promising strategy;

– the bioenergy technologies for heat and power can lead to some efficiency improvement, but higher results can be forecast from development solutions like biomass pre-treatment and thermochemical gasification, also if some innovation in the full scale exploitation of these systems must be yet realised;

– improvement in small scale co-generation units and trigeneration technologies is another possibility to increase the competitively of these systems with conventional diffused systems for energy production, chiefly in developed metropolitan areas; also the aspect of reduction of capital intensity for electricity production must be considered;

– the treatment of different type of wastes (incineration of MSW, anaerobic digestion of organic residues) requires, in account of the difficult characteristic of the treated incoming flux, very specific and costly technology, and also high operating costs, but the credit from the right destination of wastes can represent an important benefit;

– process residues, like black liquor from pulp and paper industry, biogas from sugarcane, wood residues can also represent important high calorific value fluxes, that can be used to produce heat or electricity;

– bio-methane obtained by different technologies is an important transformation product from biogas; its destination to use in substitution of other automotive fuels, or immission in grid for natural gas can represent a very efficient solution, useful at the same time to avoid local impact phenomena.

Future scenarios and inventories for biomass and connected possibilities

The future for the bioenergy is fundamentally connected with availability of sufficient biomass for different productions (biofuels or thermal or electric power), and very strictly with the use of soil, taking into account strong competition with food production, and industrial non-energy sectors (pulp and paper, building materials).

The fundamental aspects that must be considered are as follows:

– there is a large possibility for increase by utilisation of energy crops in different types of land (there is plenty of surplus land that could be converted into energy crop plantations), but the competition with other land use and the process potential complexity in order to arrive to high efficiencies for these feedstock must be carefully considered;

– large volumes of residual organic wastes can find a right valorisation chiefly by transformation in gaseous fuels (biogas for direct use, bio-methane to be traded), but the compatibility of these valorisation technologies must be taken into account;

– the forest biomass is a traditional, well consolidated source for thermal energy, and today also for co-generation, and an higher utilisation of it can be quite easily forecast, but the aspect of the forest as a carbon sink must lead to limitation of the improvement in this sense, and also consideration about biodiversity must be taken into account.

Environmental benefits (climate change)

One of the fundamental drivers in the implementation of bioenergy consists in its positive effect in GHG emission limitation, in account of the carbon balance of the whole utilisation of biomass to produce energy, taking into account all the phases of the cycle.

For the definition of this balance, it is necessary to consider the following steps:

– definition of land use, and modification of it, to be destined to production of biomass; the differential in the capacity to act as a carbon sink for the original destination of land and the new destination must be considered;

– evaluation of GHG contribution from the phases of production and harvesting of biomass, chiefly with reference to production and use of fertilisers;

– pre-treatment, drying, transformation of the harvested biomass that is required to produce the feedstock for the energy production (in this phase very often it is necessary to consider use of fossil fuels);

– thermal treatment of biomass, and direct emission of CO2 (as concerns this point, it is very interesting the possibility to consider the option of CCS, leading to a negative emission of GHG, in consideration of the absorption of gas from atmosphere during photosynthesis without subsequent emission),

– destination of wastes and residues, and their eventual impact in terms of GHG generation.

All the above-considered steps must be evaluated with a complete LCA (Life Cycle Assessment); while many specific case results are present in literature as concerns specific results, and consequent significance in term of GHG emission limitation and benefit.

Some results, for the different cases of power production(heat and/or electricity) or biofuels utilisation are useful for indication, but it is very important to take into account that these results cannot absolutely be generalised, as they strictly depend on local production conditions, pre-treatment schemes, energetic conversion efficiency, use of residuals and by-products.

By taking into account mass balances, it is possible to obtain an indication of greenhouse gas emission from different biomass, compared with the gas or coal production, taking in account the strict emission from combustion and the common agricultural practice; it is very evident the substantial advantage in comparison. But, if also the impact from land use change is taken into account, quite different results have been reported, in comparison with natural gas; it is clear that, depending on the original use of land, quite different situations can arise, from very positive in case of no land use change, to quite negative in case of conversion from grassland, that has an high potential for carbon entrapment.

Environmental balance, assessment of local effects

In order to evaluate the local consequences of energy production it is fundamental to consider the instrument of environmental balance: it consists in the comparison between the introduced pollutant loads deriving from the assumed scenario of energy production, and the pollutant loads that can be considered as eliminated, in account of the substitution of existing energy sources.

This instrument, in its more simple application, considers only the stack emissions, and is based on energy and mass balances for the compared systems (the new one and the existing scenario), by considering the plant impact factors of these systems (fluxes of emitted pollutants).

The environmental balance in this form is of simple evaluation and of a structure that can be very easily reconstructed and checked; it leads to a result that can be immediately appreciated [13–15].

From the other side it is probably less correct and of lower general value in comparison with an evaluation conducted with the tool of Life Cycle Assessment: in fact it considers the stack emissions only, and it doesn't take into account the complete process structure, that comprises also fuel production, pre-treatment and other preliminary operations. An example of all the process considered with the LCA methodology for the energy production from renewable or fossil sources is reported in Fig. 2.

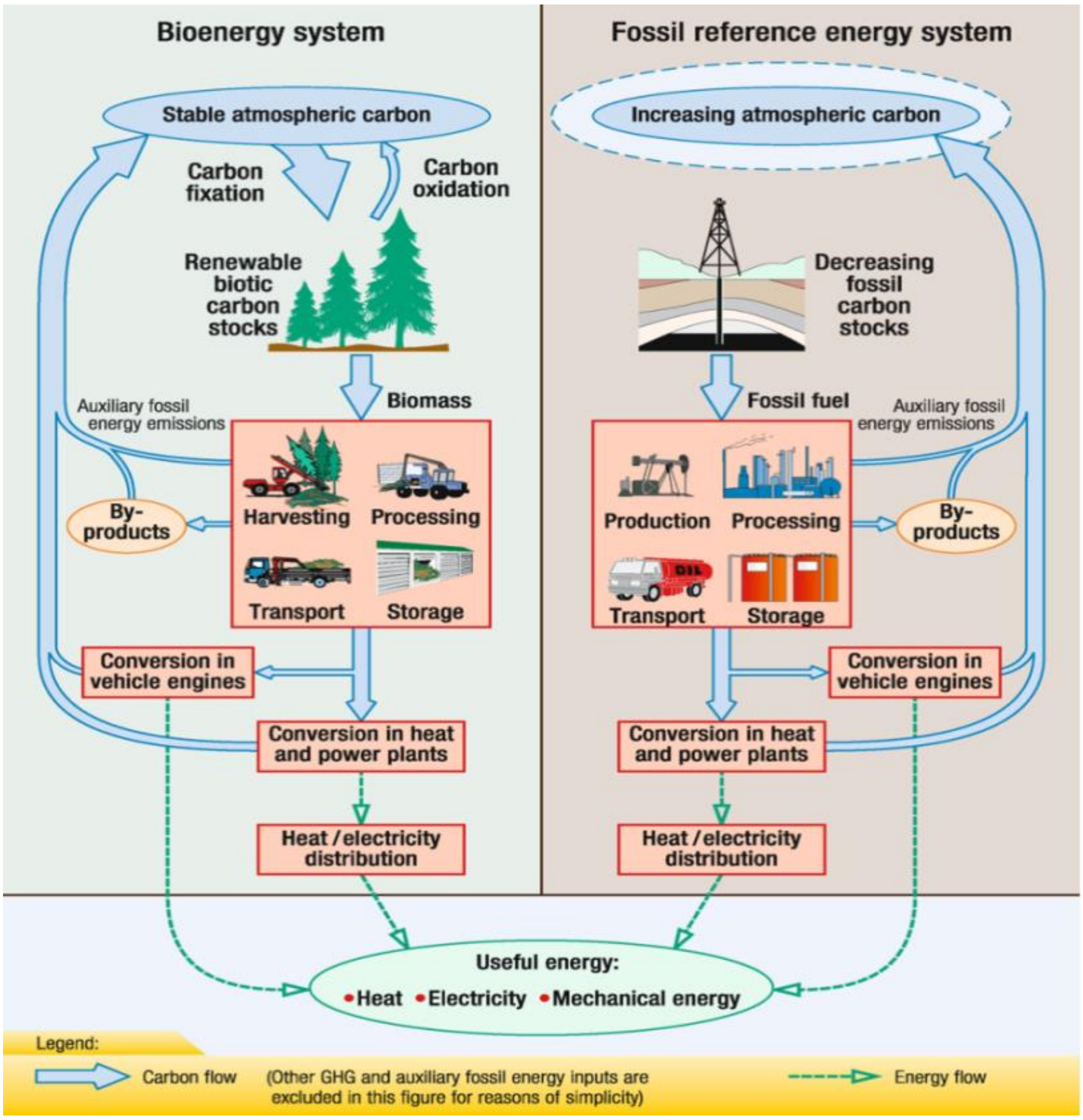

Fig. 2. Full fuel chains for comparison of bioenergy and fossil energy system [16]

This estimation is a substantial information in the assessment of compatibility for a proposed solution, but it doesn't correspond immediately to an evaluation of the consequence of the activation of an energetic system on the quality of the receiving environment (air quality chiefly, but also quality of soil, or characteristics of surface or underground waters interested to emissions).

The evaluation of this modification of quality must be considered the true indicator for the compatibility, and at the end it determines the acceptability of a proposed energy solution; it depends from its results.

First of all it is necessarily to know the specific emission and dispersion for the considered site, and so it must consider specific well determined and not literature values; but chiefly it is important that the evaluation must be able to describe all the mechanisms and the phenomena that transfer the pollutant from the source to the surroundings targets.

In order to implement this knowledge, it is required a predictive model that describes the physical, physico-chemical and chemical phenomena that are involved in the transfer of pollutants; all the specific parameters that are involved in the transfer and transformation phenomena must be known.

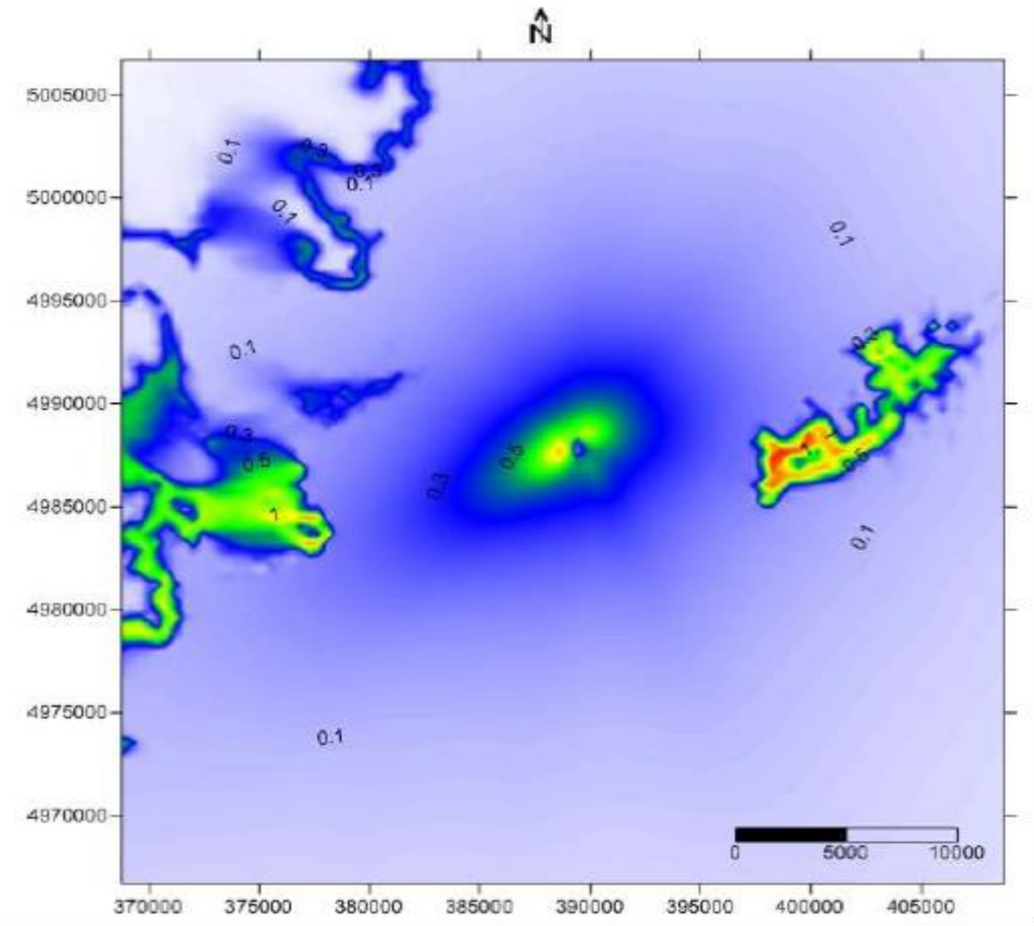

Fig. 3. Assessment of local impact [17]

Against the complication of the calculation, it must be observed that the final result (an example is reported in Fig. 3) concerning the air quality for a new biomass thermoelectric plant is absolutely more meaningful in comparison with simple emission environmental balance; in some cases it can lead to estimations that are different from first instance environmental balance results [18, 19].

Definition of planning criteria for impact limitation

In order to limit the environmental impact of energy production it is very important to consider the aspect of localization, with reference both to large plants, as thermoelectric generation plants, and also to distributed small plants, as vehicles, domestic boilers, or micro-cogenerators.

In fact the environmental impact aspects that are deriving from different phases of energy production are strictly linked to the area of operation: many aspects must be considered in this sense, as the access to raw materials, the loads arising from transport, the effect of emission on the quality of receiving media, the possibility to use in its integrality (heat and power) the produced energy.

All these aspects are strictly bound to the position where a plant or an apparatus is operating, and so it is very important to consider where the structure is located.

In order to correctly evaluate all these aspects, the informations that must be required about the receiving area are as follows [20, 21]:

– presence or possibility to obtain biomass useful for energy production;

– possibility to use resources, marginal soils, secondary fertilizers for the growth of sustainable resources destinated to fuel production;

– connection to transport systems for solid fuels;

– possibility to transfer residual heat to existing or proposed district heating networks, or to large industrial users;

– conditions of local air stability, dispersion conditions, stagnation possibilities;

– possibility to use residual ashes from solid fuels combustion for operations of soil remediation;

– presence of common transport systems for needs of mobility of the population and potential use of biofuels.

The informations so required can be obtained by a careful analysis of the area where the energy production must be realized; this analysis is directed to the evaluation of natural aspects and perspectives of resilience, verification of infra-structural situation, consideration of the present industrial activities, consideration of social and operative projects for the development of the considered area.

From a coordinated lecture of all these aspects, the public authority can obtain elements for a planning activity, directed also to verification of aspects of environmental compatibility [22].

Ethical and social considerations

Besides to considerations concerning positive aspects as regards climate change benefits, and right evaluation of compatibility with reference to different environmental aspects, as it was indicated in the previous points, it is necessary also to evaluate the compatibility from the point of view of ethical and social considerations.

The principal aspects that must be considered are:

– ability of modern bioenergy to provide safe and cheap energy services for the poorest populations: these possibilities, strictly required for an enhancement of living conditions of many countries, are connected with definition of resource availability and clarifying of competitive uses, economic access and reliability of solutions, financing;

– consequences for agro-industrial development and job creation: the creation of small companies directly operating on the territory, the development of rural and transformation employment, and infrastructures are very important implications for this type of development;

– improvement of the structure of agricultural activities, with direct involvement of farmers in the production and use of biofuels, with particular emphasis on second generation, avoiding competition with food products and consequent cost increase; the capacity building is an important option for this improvement;

– priority for food supply and food security: taking into account the fundamental priority of food satisfaction of under-developed areas, it is necessary to develop an analytical framework to fully understand the long term impacts of expanded bioenergy production; also an enhancement in agricultural productivity and sustainability, by conserving water and by improving soil fertility, is useful to diminish the competition of bioenergy;

– the diversification of global fuel and energy supply can have a positive effect on the global energy market, with a redistribution of producers and a lower risk of artificial cost structure; the trade policy of products should also be positively affected by this energy transformation;

– no additional negative biodiversity impacts: a correct feedstock choice, and improvement of soil health in the framework of the best land use can preserve biodiversity, minimise chemicals use for fertilisation, reduce water needs; also a good management of residues and wastes can have positive effects on maintain ecosystem health.

Conclusions

Bioenergy exploitation, devoted to residual treatment, energy crops valorisation, agricultural activities enrichment can lead to important advantages as concerns climate change limitation and resources best use; the potential negative aspects connected to local impact, localisation limits, territorial, ethical and social aspects must be considered.

REFERENCES

1. Boman, U. R., Turnbull, J. H. (1997), Integrated biomass energy systems and emissions of carbon dioxide, Biomass and Bioenergy, 13. – P. 333–343.

2. Dornburg, V., Van Dam, J., Faaij, A. (2007), Estimating GHG emission mitigation supply curves of large – scale biomass use an a country level, Biomass and Bioenergy, 31. – P. 46–65.

3. Albertazzi, S., Basile, F., Brandin, J., Einvall, J., Hulteberg, C., Fornasari, G., Rosetti, V., Sanati, M., Trifirò, F., Vaccari, A. (2005), The technical feasibility of biomass gasification for hydrogen production, Catalysis Today, 106. – P. 297–300.

4. Bridgwater, A. V. (2005), The technical and economic feasibility of biomass gasification for power generation, Fuel, 74. – P. 631–653.

5. Caputo, A.C., Palumbo, M., Pelagagge, P. M., Scacchia, F. (2005), Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables, Biomass and Bioenergy, 28. – P. 35–51.

6. Hanaoka, T., Inove, S., Uno, S., Ogi, T., Minowa, T. (2005), Effect of woody biomass components on air – steam gasification, Biomass and Bioenergy, 28. – P. 69–76.

7. Hohenstein, W.G., Wright, L.L. (1994), Biomass energy production in the United States: an overview, Biomass and Bioenergy, 6. – P. 161–173.

8. Hustad J., Skreiberg Ø., Sonju O. (1995), Biomass combustion research and utilization in IEA countries, Biomass and Bioenergy, 9. – P. 235–255.

9. Van Den Broek, R., Faa, Ij A., Van Wick, A. (1996), Biomass combustion for power generation, Biomass and Bioenergy, 11. – P. 271–281.

10. Maniatis, K. (2002), Progress in Biomass Gasification: An Overview.

11. IEA Bioenergy (1998), The role of bioenergy in greenhouse gas mitigation, Position paper, IES Bioenergy, New Zealand.

12. IEA (International Energy Agency) (2012), Technology roadmap, Bioenergy for heat and power, available at: http://www.iea.org/publications/freepublications/publication/bioenergy.pdf, last access on 14 May 2015.

13. Genon, G., Brizio, E. (2008) Perspectives and limits for cement kilns as a destination for RDF, Waste Management, 28. – P. 2375–2385.

14. Panepinto, D., Brizio, E., Genon, G. (2014), Atmospheric pollutants and air quality effects: limitation costs and environmental advantages (a cost – benefit approach), Clean Technologies and Environmental Policy, 16(8). – P. 1805–1813.

15. Martire, S., Castellania, V., Sala, S. (2015), Carrying capacity assessment of forest resources: Enhancing environmental sustainability in energy production at local scale, Resources, Conservation and Recycling, 94. – P. 11–20.

16. Cherubini, F., Bird, N. D., Cowie, A., Jungmeier, G., Schlamadinger, B., Gallasch, S.W. (2009), Energy- and greenhouse gas-based LCA of biofuel and

bioenergy systems: Key issues, ranges and recommendations, Resources, Conservation and Recycling, 53. – P. 434–447.

17. Panepinto, D., Genon, G. (2014), Environmental evaluation of the electric and cogenerative configurations for the energy recovery of the Turin municipal solid waste incineration plant, Waste Management & Research, 32. – P. 370–380.

18. Carreras-Sospedra, M., Vutukuru,, S., Brouwer, J., Dabdub, D. (2010), Central power generation versus distributed generation – An air quality assessment in the South Coast Air Basin of California, Atmospheric Environment, 44. – P. 3215–3223.

19. Panepinto, D., Genon, G. (2011), Environmental balance study for the construction of a biomass plant in a small town in Piedmont (Northern Italy), WIT Transactions on Ecology and the Environment, 143. – P. 279–290.

20. Genon, G., Torchio, M., Poggio, A., Poggio, M. (2009), Energy and environmental assessment of small district heating systems: Global and local effects in two case-studies, Energy Conversion and Management, 50. – P. 522–529.

21. Santoyo-Castelazo, E., Azapagic, A. (2014), Sustainability assessment of energy systems: integrating environmental, economic and social aspects, Journal of Cleaner Production, 80. – P. 119–138.

22. Pohekar, S.D., Ramachandran, M. (2004), Application of multi-criteria decision making to sustainable energy planning – A review, Renewable and Sustainable Energy Reviews, 8. – P. 365–381.